Underwater photo-identification of sicklefin lemon sharks, *Negaprion acutidens*, at Moorea (French Polynesia)

by

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ABSTRACT. - Shark feeding is a controversial recreational activity that may alter shark behaviour. In order to investigate possible behavioural changes at the level of the individual, it is necessary to recognise each shark underwater and in a non-intrusive way. In this study, we tested a protocol based on natural marks on fins, and coloured spots and scars on the body to differentiate individual sicklefin lemon sharks. We found that a feeding group, aggregated for 26 months at a northern location off Moorea Island, comprised 32 animals (19 females and 13 males), identified from 2589 observations made over 541 dives. Post-dive photo-identification of individual sharks was a reliable technique, whereas a high level of skill was required to ensure an instantaneous identification underwater. However, direct underwater identification of individual sharks can be of potential use in shark behavioural studies.

RÉSUMÉ. - Photo-identification des requins limon faucille, *Negaprion acutidens*, à Moorea (Polynésie française).

Le nourrissage des requins (communément appelé 'shark feeding') est une activité récréative controversée qui peut altérer le comportement des requins. Afin d'étudier les possibles changements de comportement des individus, il est nécessaire d'être capable de reconnaître chaque requin en plongée sans leur porter préjudice. Dans cette étude, nous testons un protocole utilisant les marques naturelles sur les nageoires, ainsi que des taches colorées et des cicatrices présentes sur le corps des requins afin de différencier chaque requin limon faucille, *Negaprion acutidens*, à Moorea en Polynésie française. Nous avons observé qu'un groupe de requins s'étant rassemblé pendant 26 mois sur un site de nourrissage situé dans la partie nord de l'île de Moorea, était composé de 32 animaux (19 femelles et 13 mâles) identifiés à partir de 2589 observations réalisées à l'issus de 541 plongées. L'analyse des clichés de retour de plongée s'est avérée une technique efficace, alors que des compétences spécifiques ont été requises pour garantir une identification instantanée en plongée. Cependant, une identification directe en plongée de chaque individu peut permettre d'effectuer des études sur le comportement des requins évoluant dans leur milieu naturel.

Key words. - Carcharhinidae - *Negaprion acutidens* - Sicklefin lemon shark - French Polynesia - Moorea Island - Shark feeding - Sighting-resighting - Visual identification.

Although the Pacific lemon shark *Negaprion acutidens* (Rüppell, 1837) was described before the Atlantic species *Negaprion brevirostris* (Poey, 1868), very little information about its biology and behaviour are available, except some data on growth and reproductive biology (Stevens, 1984; Dulvy and Reynolds, 1997) and nutrition (Salini *et al*., 1992; White *et al*., 2004). Meanwhile, the Atlantic species has been specifically and intensively studied over the past twenty years, in particular by Gruber and collaborators both in Caribbean (Gruber *et al*., 1988; Dibattista *et al*., 2007) and Brazilian waters (Freitas *et al*., 2006). The sicklefin lemon shark is a widely distributed Indo-Pacific coastal shark that ranges from Eastern Africa to French Polynesia. The species is of long-standing commercial interest for human consumption (Compagno, 1984), but more recently it has also become one of the most impressive focal species in shark feeding activities in the central and eastern Pacific. Except for a study by Scharfer (2003) there are no scientific studies that deal with the controversial recreational activity, particularly in relation to critical issues such as increased potential risk of attacks on humans and the effect of feeding on the biology of shark populations. For countries such as French Polynesia that are concerned by the controlled development of feeding as an attractive tourist activity, but also by the potential effects on shark populations, lemon sharks in particular, there is a need for objective data. Collection of these data depends to a large extent on the capacity to identify individual sharks. Photo-identification has shown great potential, despite some inconveniences linked to its technical implementation (Cailliet, 1996). This technique was used for marine mammals such as humpback whales (Katona *et al*., 1979), dolphins (Mizroch and Bigg, 1990; Markowitz *et al*., 2003; Mazzoil *et al*., 2004), for basking sharks (Sims *et al*., 2000) and recently for marine crustaceans (Frisch and Hobbs, 2007). Shark photo-

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identification is usually based on spot or colour patterns and scars on specific areas of the body, such as recently described for white sharks (Domeier and Nasby-Lucas, 2006), and whale sharks (Meekan *et al*., 2006; Graham and Robert, 2007). Bansemer and Bennett (2008) recently tested the use of spots on flanks of *Carcharias taurus* to identify individuals and to monitor shark populations. Compared to these species, the lemon shark presents the inconvenience of being of a relatively uniform yellow colour. However, Castro and Rosa (2005) faced the same problem with nurse sharks in Brazil and used natural marks on fins for successful estimation of their population.

In this paper, we test whether natural marks on fins, plus coloured spots and scars on sicklefin lemon sharks are suitable for photo-identification of individual shark in a feeding-related aggregation off Moorea Island (French Polynesia). If successful, this first step will allow useful data to be collected and used in a potential behavioural study of this population.

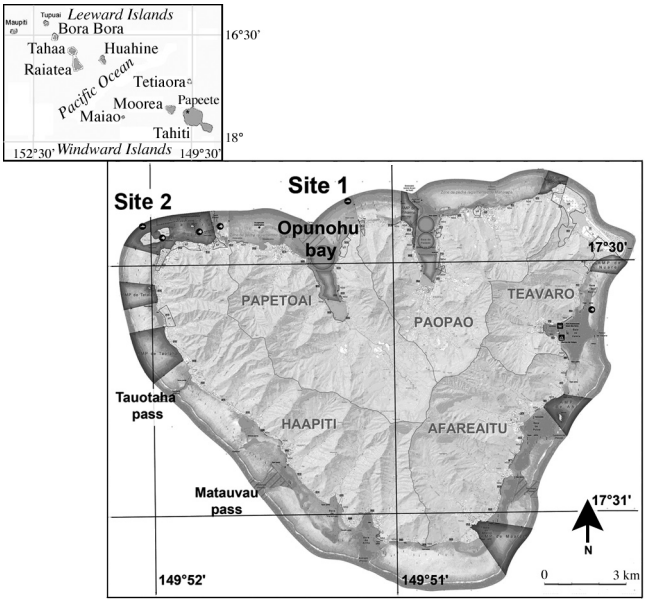

Figure 1. - Location of shark feeding sites in Moorea Island (French Polynesia). *[Localisation des sites de nourrissage des requins sur l'île de Moorea (Polynésie française).]*

MATERIAL AND METHODS

Study area

The study was conducted at Moorea Island, French Polynesia (17°30' S; 149°51' W). Moorea authorities implemented a Management Plan for Marine Environment (Plan de gestion de l'espace maritime - PGEM) in October 2004 which included zoning different human activities. Two zones were defined in Papetoai (site 1) and Haapiti (site 2) for shark feeding activities (Fig. 1). Our specific study area is site 1 which encompasses a surface of 2.2 km in length (149°50.67' to 149°51.39' W) and 100 m in width, on the outer slope from 5 to 25 m of depth. Shark feeding activities in Moorea started in 1999 with three diving centres, and only one was still operating from 2004 to 2007.

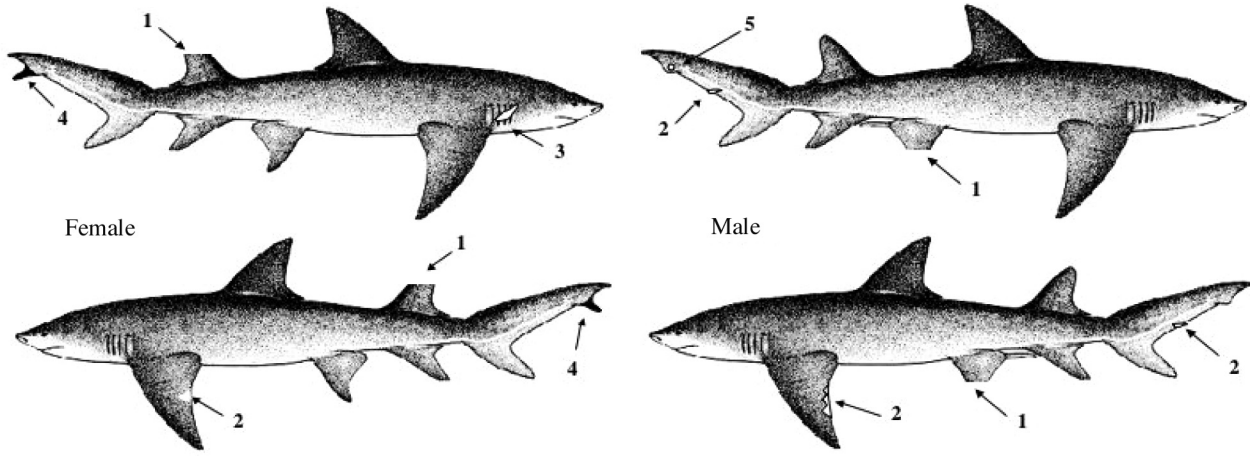

Figure 2. - Example of individual schemes for visual identification of sharks on predefined templates. Left: female with (1) a truncated apex of the second dorsal fin, (2) a notch on the left pectoral fin, (3) a scar on gills on the left side and (4) an extended subterminal notch on the caudal fin. Right: male with (1) a truncated apex of the left pelvic fin, (2) cuts in the median zone of the posterior margin of the caudal fin and on the posterior margin of the left pectoral fin, and (5) a white spot on the right side of the subterminal notch of the caudal fin. *[Exemple de fiches individuelles pour l'identification visuelle des requins sur des patrons prédéfinis. A droite: une femelle avec (1) l'apex de la seconde nageoire caudale tronqué, (2) une encoche sur la nageoire pectorale gauche, (3) une cicatrice au niveau des fentes branchiales gauches et (4) une expansion de l'encoche subterminale sur la nageoire caudale. A gauche: un mâle avec (1) l'apex de la nageoire pelvienne gauche tronqué, (2) des coupures sur la zone médiane de la marge postérieure de la nageoire caudale et de la nageoire pectorale gauche, et (5) une tache blanche sur le côté droit de l'encoche subterminale de la nageoire caudale.]*

Table I. - Criteria for visual and photo-identification of the lemon shark population at site 1 off Moorea Island. RF: Right fin; LF: Left fin; RS: Right side; LS: Left side; BS: Both sides; PM: Posterior margin; AM: Anterior margin; D1: First dorsal fin; D2: Second dorsal fin; SN: Subterminal notch; SE: Skin excrescence; TA: Truncated apex; MA: Missing apex; CF: Caudal fin; AF: Anal fin; PF: Pelvic fin; MZ: Median zone; UZ: Upper zone; LZ: Lower zone. *[Critères d'identification visuelle et photographique de la population du requin limon faucille sur le site 1 sur la pente externe de l'île de Moorea. RF : Nageoire droite; LF : Nageoire gauche ; RS : Côté droit ; LS : Côté gauche ; BS : Des deux côtés ; PM : Marge postérieure ; AM : Marge antérieure ; D1 : Première nageoire dorsale ; D2 : Seconde nageoire dorsale ; SN : Encoche subterminale ; SE : Excroissance cutanée ; TA : Apex tronqué ; MA : Apex manquant ; CF : Nageoire caudale ; AF : Nageoire anale ; PF : Nageoire pelvienne ; MZ : Zone médiane ; UZ : Zone dorsale ; LZ : Zone ventrale.]*

ID	Criterion 1		Criterion 2				Criterion 3	
	Gender	Length (m)	Caudal fin	Dorsal fins	Pectoral fins	Anal and pelvic fins	Spots	Scars
F01	FEMALES	2.8			RF 2 cuts PM	TA on AF		RS 1 vert. on caudal peduncle x 20 cm
F02		2.4	RS SE in MZ		LF 2 cuts PM		LS white MZ	
F06		2.4					LS white after gill slits + RS belly MZ	RS 1 on gill slits
F08		2.3		RF black spot MZ				RS 1 on labial furrows
F11		2.8					BS white CF on SN	LS 1 on eye
F13		2.8		D1 concave PM			RS white flank MZ	
F15		2.4		D2 MA	RF 1 cut PM			
F16		2.6	Notch in LZ		LF 1 cut PM			
F17		2.6		D2 MA + RS black spot	LF 2 cuts PM			
F20		2.5					BS white CF on SN	
F21		2.7		D2 MA	LF 1 cut PM			
F22		2.3					RS 2x2 superposed black spots (before and after gill slits)	
F25		2.5	TA		RF 3 cuts PM			
F26		2.2	SE under SN + cut in MZ		LF 1 cut PM			
F27		2.5					RS white CF UZ	LS flank 1 vert. x 30 cm
F29		2.1		D2 square apex				
F30		2.7		D2 1 vert. 20 cm cut (scar) on Apex			BS white CF on SN	
F32		2.2	Extended SN					
F33		2.7	TA and LS SE in MZ	D2 2 vert. cuts on apex	LF 3 cuts PM			
M03	MALES	2.4		D1 flat apex		RS 3 cuts PM PF		
M04		2.5	Cut median		Bite on LP	LS MA on PF	RS of CF white	
M05		2.5			LF cut PM	LS cut PM PF		BS on gills
M07		2.5	LS 1 SE in LZ		RF SE AM		BS white CF on SN	
M09		2.5	2 SE under SN				LS white CF on SN	
M10		2.3		D2 MA	RF 1 cut PM		BS white CF on SN	
M12		2.5	MA on SN + extra notch below					
M14		2.3	SN missing					
M18		2.5			LF 1 cut PM proximal zone			
M19		2.1	1 SE under SN		LF 3 cut PM			
M28		2.5	Sharp upper apex					
M31		2.2	Round upper apex		RF irregular PM			RS 1 on first gill
M34		2,4	RS 1 SE under SN		RF 1 cut PM	RS PF concave		

Feeding activity

Feeding sessions in site 1 (Fig. 1) were implemented through dives at a depth of 20 to 25 m, which lasted from 60 to 100 min depending on the breathing mixture (either normal air or 33% Nitrox). A feeding session comprised the placement of a small cage on the substrate that enclosed tuna discards, such as heads and fins from 1.5 to 2.5 kg fish. The cage prevented the sharks from reaching and eating the food too quickly, and allowed divers to observe the sharks from a distance of about two to five metres from the cage. The distance between divers and sharks was dependent on the shyness of the sharks. The food was released 15 min before the end of the dive.

Criteria for identification

The first criterion for underwater shark identification was both the gender and the size of the animal. The second criterion relied on characteristics of the fins (caudal, dorsal, pectoral, pelvic and anal). These characteristics can be one or several scars or excrescences of tissue (such as warts) on the surface of the fin, or a marginal loss of tissue on the margins of the fin (after a bite), which evolves into a truncated apex or a single cut depending on its severity. Specific attention was given to the particularities of the subterminal notch located on the top posterior margin of the caudal fin. The third criterion relied on scars or coloured spots on the body of the shark (excluding fins). Each criterion was compiled on waterproof sheets with shark scheme template during the underwater observation, as shown in figure 2. The side of the body was also recorded, as unilateral observations may not provide enough information to identify a particular individual.

Data collection

The data were collected during 541 feeding sessions which were implemented during 26 months between October 2004 and February 2007. The diver in charge of providing the food to the sharks was equipped with a 3 megapixel digital camera (SONY and Ikelite housing). Following an opportunistic approach, images of the entire body and of specific areas of the sharks were taken during each dive.

RESULTS

The dives at site 1 allowed 2589 observations. 32 sharks were distinguished, of which 19 were females and 13 were males, based on morphological characteristics in order of priority: caudal fins, dorsal fins, pectoral fins, anal and pelvic fins, plus the potential presence of coloured spots or scars on the body (Tab. I). Specific and visual examples of the criteria used such as truncated apex, notches, scars, spots or skin excrescences are given in figure 3.

DISCUSSION

Photo-identification strictly based on colour patterns has been shown to be reliable if the focal animals have at least two distinct colours on specific areas of their bodies, such as the design of the white colouration on the ventral side of the fluke in sperm whales (Katona *et al*., 1979), the extension of the white colouration on the gill flaps of white sharks (Domeier and Nasby-Lucas, 2006) or the spots and stripes near the posterior gill slit of whale sharks (Meekan *et al*., 2006). Data analysis with software that uses information-theoretic scores of match parsimony provides a very reliable method for mark-recapture studies without resorting to invasive marking techniques (Speed *et al*., 2007). However, automated spot-recognition programs used for analysis of photo-identification require natural, significant and extended differences in the colour patterns of the studied animals. In the current study, white or black spots did occur on what were otherwise homogeneously coloured lemon sharks, but the frequency of occurrence of spots was low and precluded their use as the main basis for shark identification as it was used for other species with uniform body colouration (Bansemer and Bennett, 2008). In addition, although these spots were useful on a temporal scale of several weeks or months, they showed a poor resilience over years. The efficiency of our method mainly relied on the observation of natural marks, similar to the approach used to assess a population of nurse sharks in Brazilian waters (Castro and Rosa, 2005). Therefore, in contrast to most photo-identification methodologies so far implemented (Domeier and Nasby-Lucas, 2006; Meekan *et al*., 2006; Speed *et al*., 2007), colour considerations were only a complementary and secondary criterion.

The majority of marks, other than natural spots, were consistent with shark-inflicted bite injuries, considered to result primarily from intra-specific interactions, and external injuries inflicted by hooks. These marks were observed to vary with time. Given the ability of sharks to regenerate tissue (Reif, 1978; Domeier and Nasby-Lucas, 2006), in particular carcharhinids (Heupel *et al*., 1998), the quantity of tissue lost is of major importance in the longevity of visible wounds useful for shark identification. There were several examples observed in our study that showed this regenerative characteristic of sharks. A male lemon shark was photographed in October 2004 with a 20 cm vertical laceration, but with no loss of tissue, on the second dorsal fin. This injury had healed significantly within two months by December 2004 and was difficult to distinguish a year later in October 2005 (Fig. 4). However, based on our study we found that when there was a significant tissue loss, such as fin notches and truncated apices of fins, these did not change as markedly over time and they were reliable features for individual shark recognition over extended periods of time. This obser-

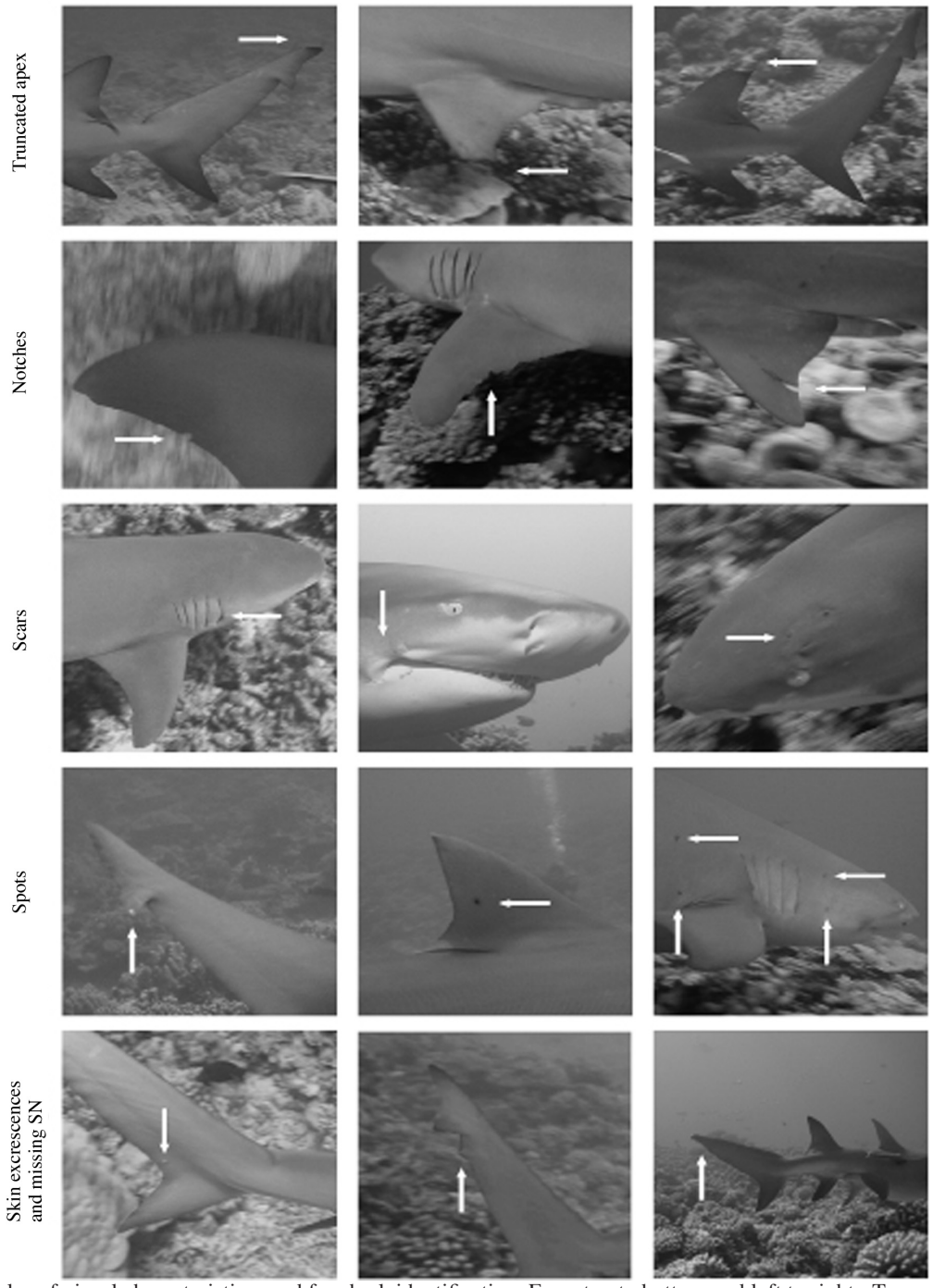

Figure 3. - Examples of visual characteristics used for shark identification. From top to bottom and left to right : Truncated apex : F25 (Caudal fin), M04 (Left pelvic fin), F15 (Second dorsal fin); Notches on fins : F02 (Left pectoral fin), M05 (Left pectoral fin), M05 (Left pelvic fin) ; Scars : M31 (Gills , left side), F08 (Mouth, right side), F21 (Top of the head, left side); Spots : F20 (White on subterminal notch, right side), F08 (Black on dorsal fin, right side), F22 (Black around gills, right side); Others : F02 (Skin excrescence on the median zone of the caudal fin, right side), M19 (Skin excrescence below the subterminal notch, posterior margin), M14 (Absence of the subterminal notch). *[Exemples de caractéristiques visuelles utilisées pour l'identification des requins. De haut en bas et de gauche à droite : Apex tronqué : F25 (Nageoire caudale), M04 (Nageoire pelvienne gauche), F15 (Seconde nageoire dorsale); Encoches sur les nageoires : F02 (Nageoire pectorale gauche), M05 (Nageoire pectorale gauche), M05 (Nageoire pelvienne gauche) ; Cicatrices : M31 (Fentes branchiales , côté gauche), F08 (Bouche au niveau du sillon labial, côté droit), F21 (Au dessus de la tête, côté gauche); Taches : F20 (Blanche sur l'encoche subterminale, côté droit), F08 (Noire sur la nageoire dorsale, côté droit), F22 (Noire autour des fentes branchiales, côté droit); Autres : F02 (Excroissance de peau sur la zone médiane de la nageoire caudale, côté droit), M19 (Excroissance de peau sous l'encoche subterminale, marge postérieure), M14 (Absence d'encoche subterminale).]*

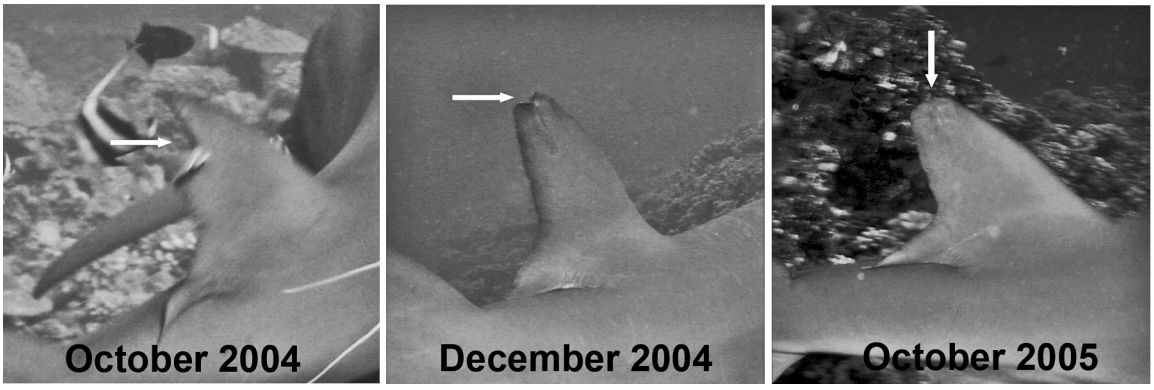

Figure 4. - Progressive and rapid healing of a 20 cm vertical cut on the second dorsal fin of the male lemon shark M10 from October 2004 to October 2005. *[Cicatrisation progressive et rapide d'une entaille verticale de 20 cm sur la seconde nageoire dorsale du requin limon faucille mâle M10 d'octobre 2004 à octobre 2005.]*

vation is in contrast to that of Pratt and Carrier (2001) who found that the natural marks in nurse sharks healed rapidly, grew or changed in time.

Our results suggest the recognition of individual sicklefin lemon sharks was best achieved primarily through the use of wound occurrence, particularly to the fins, augmented by the occurrence of natural spots on the body. Unambiguous identification of individual sharks was generally possible after a dive, based on analysis of images. The ability to quickly identify any of the 32 lemon sharks while underwater at our study site was also possible, but required a high level of experience. As behavioural data collection necessitates instantaneous recognition of individuals underwater the specific skills that our team has acquired, coupled with the possibility to regularly observe these sharks throughout the year, provides us with an excellent opportunity to assess the long term effects of feeding on a coastal shark population.

Acknowledgements. - This study was implemented thanks to the financial support of the Direction à l'Environnement (DIREN) of French Polynesia and the scientific support of the Coordination Unit of the Coral Reef Initiatives for the Pacific (CRISP Programme), based in Noumea (New Caledonia). We would like to thank the private diving company Top Dive in Moorea for logistical support and René Galzin at the CRIOBE research institute, for scientific support.

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Reçu le 24 janvier 2008.
Accepté pour publication le 6 février 2009.